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An Economic Model for Routine Analysis of the Welfare Effects of Regulatory Changes

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For information, please contact:

Kenneth W. Forsythe, Jr., Ph.D.

USDA:APHIS:VS
Centers for Epidemiology and Animal Health Center
for Animal Disease Information and Analysis
2150 Centre St. Bldg B
Fort Collins, Colorado 80526

Telephone: 970-494-7285 Fax: 970-490-7999

e-mail: Kenneth.W.Forsythe@aphis.usda.com

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INTRODUCTION

Purpose and Potential Applications

The purpose of developing the economic model discussed herein is to have and maintain a routine systematic method of analyzing the "relative cost" or "cost-effectiveness" of different strategies or control measures of Veterinary Services program diseases (e.g., brucellosis and pseudorabies). The economic model provides a means of evaluating:

(1) Benefits and costs of control programs for the foreseeable future under current program policies and activities; and

(2) Provides methods for analyzing changes in policies and activities.

A key goal for the model is reducing turnaround time for analyses.

As stated in Lichtenberg and others, "To be useful in policy assessments, welfare methodologies must meet certain requirements. First, they must provide estimates of the efficiency impacts of alternative policies, measured by changes in net social surplus. Second, estimates of the distributional effects of proposed policies must be provided. Third, they must be able to utilize data constructed without regard to economic needs by engineers and natural scientists (e.g., entomologists or agronomists). Finally, they must be capable of producing results on short notice."

Market and equity effects of policy or activity changes can be measured with the model. The net benefits and costs of these changes can be determined from estimates of

(1) The yield or unit cost effects of the changes on affected livestock operations,

(2) How market prices and quantities adjust to these effects,

(3) How consumers and producers are affected by the adjustments, and

(4) Government expenditures required to make the changes.

There are many potential applications for the model. The model can be used to evaluate changes in the efficiency of surveillance systems, diagnostic tests, cleanup programs, etc. The model is focused primarily on domestic Veterinary Services disease programs but has more general applications, such as in regulatory impact analyses for measuring the effects of changes in regulations governing trade in animals and animal products. The model is equally applicable to plant pest issues.

The documentation that follows is written for an audience that includes both economists and biological scientists who may be interested in employing the model as part of an evaluation of regulatory programs related to plant and animal health.

Analytical Methods Applied in the Model

The economic model is an application of economic welfare analysis. Economic welfare analysis specifically evaluates how:

(1) Market prices and quantities adjust to changes in mitigation measures as well as changes in pest or disease spread, and

(2) Consumers and producers are affected by the adjustments in market prices and quantities. The effects on consumers and producers are measured in terms of changes in the difference between what consumers are willing to pay and what they actually pay for products (**consumer surplus**) and in returns to producers' fixed factors of production (**producer surplus**).

The economic model can use information regarding biological consequences as input in determining the monetary impact of disease or pest spread on producers and consumers.

Software Platform

The model was designed to be implemented on a spreadsheet platform. The model operates in most spreadsheets that have three-dimensional capability. Three-dimensional capability means that the spreadsheet, in addition to rows and columns, has pages that may be organized into a workbook. This spreadsheet-based model is very flexible and eliminates the need for redevelopment as APHIS upgrades its software and hardware systems.

Partial Equilibrium Welfare Model

The model expands on a method discussed and applied in **Lichtenberg and others**, **Ebel and others, and Forsythe and Corso**. As with any model, because it is a simplified representation of reality, it has certain limitations. Nevertheless, it can provide useful insight for decision making by allowing policy experiments to be conducted in a computer simulation.

The model is a multi-market, non-spatial, partial price equilibrium, welfare model. Multi-market means that the effects of changes in closely related markets that result from a change in any one market can be captured in the model. Non-spatial means that price and quantity effects resulting from geographic differences in market locations are not included. Therefore, price and quantity effects obtained from the model are assumed to be the average of effects across geographically separated markets. Partial price equilibrium means that the model results are based on maintaining commodity price equilibrium in a limited portion of an overall economy **(Figure 1).**

Economic sectors not explicitly included in the model are assumed to have a negligible influence on the model results. Welfare model means that consumers' willingness to pay for commodities beyond their actual price (a measure of utility known as consumer surplus) and producers' revenue beyond their variable costs (a measure of returns to fixed investment known as producer surplus) are included in the model (**Figure 2**).

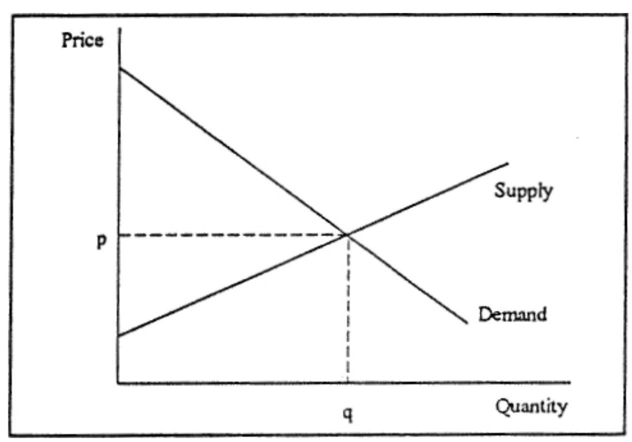

Figure 1. Supply, demand and equilibrium price and quantity.

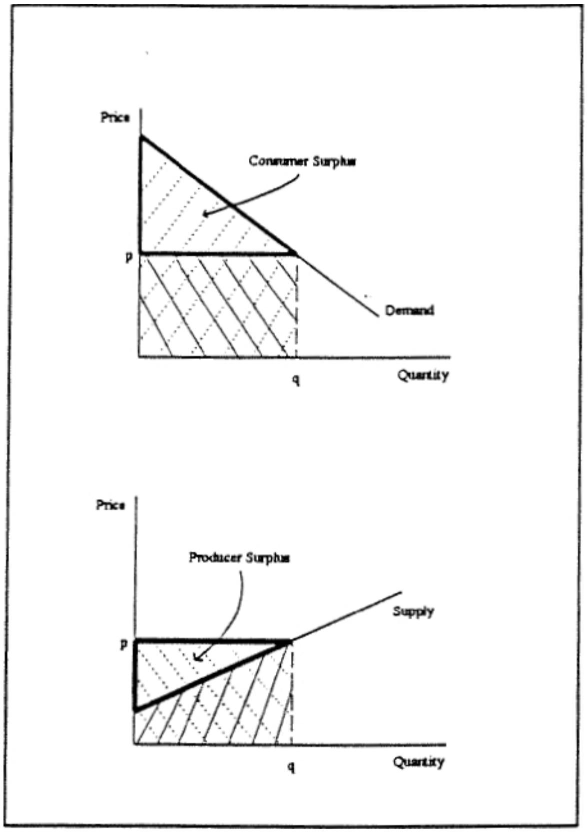

Figure 2. Consumer and Producer Surplus

Welfare effects are modeled over time to capture the effects of disease spread and control. The model disaggregates producers into $\boldsymbol{K}$ subgroups. Exporting and importing sectors of the market are also included. The model gives estimates of changes in **(a)** equilibrium prices $(\boldsymbol{P})$, **(b)** equilibrium quantities produced by each of the $\boldsymbol{K}$ subgroups $(\boldsymbol{Q_k})$, **(c)** consumer surplus $(\boldsymbol{CS})$, **(d)** producer surplus $(\boldsymbol{PS})$ in each of the $\boldsymbol{K}$ subgroups, and **(e)** the welfare effects resulting from changes in imports and exports. Cross commodity effects are included through demand and supply shifters. Effects of changes in disease status on producer's operations are modeled using parallel shifts $(\boldsymbol{a_k})$ in producers' marginal cost or supply functions $(\boldsymbol{S^k})$. This approach provides reasonably accurate approximations of small changes for any functional form of demand or supply functions. Linear supply and demand functions are used for modeling convenience.

The Market Equations

The model is based on a system of market equations including inverse domestic supply in each of $\boldsymbol{K}$ regions for the domestic market **(1)**, inverse foreign supply for the domestic market **(2)**, inverse domestic demand for domestic products **(3)**, inverse foreign demand for domestic products **(4)**, and a market clearing equation **(5)**:

(1) $$\boldsymbol{P = S^k\left(Q_{k,}a_k\right), k = 1, ..., K}$$

(2) $$\boldsymbol{P = S^m\left(Q_{m,}a_m\right)}$$

(3) $$\boldsymbol{P = D^d\left(Q_{d,}b_d\right)}$$

(4) $$\boldsymbol{P = D^e\left(Q_{e,}b_e\right)}$$

(5) $$\boldsymbol{Q_1 + ... + Q_K + Q_m = Q_d + Q_e}$$

Solving the System for Price and Quantity Changes

The system of market equations is then totally differentiated so that it can be expressed in terms of price and quantity changes.

(1.1) $$d\boldsymbol{P} = \frac{\partial \boldsymbol{P}}{\partial \boldsymbol{Q}_k} d\boldsymbol{Q}_k + \frac{\partial \boldsymbol{P}}{\partial \boldsymbol{a}_k} d\boldsymbol{a}_k, \ \boldsymbol{k} = 1,...,\boldsymbol{K}$$

(2.1) $$d\boldsymbol{P} = \frac{\partial \boldsymbol{P}}{\partial \boldsymbol{Q}_m} d\boldsymbol{Q}_m + \frac{\partial \boldsymbol{P}}{\partial \boldsymbol{a}_m} d\boldsymbol{a}_m$$

(3.1) $$d\boldsymbol{P} = \frac{\partial \boldsymbol{P}}{\partial \boldsymbol{Q}_d} d\boldsymbol{Q}_d + \frac{\partial \boldsymbol{P}}{\partial \boldsymbol{b}_d} d\boldsymbol{b}_d$$

(4.1) $$d\boldsymbol{P} = \frac{\partial \boldsymbol{P}}{\partial \boldsymbol{Q}_e} d\boldsymbol{Q}_e + \frac{\partial \boldsymbol{P}}{\partial \boldsymbol{b}_e} d\boldsymbol{b}_e$$

(5.1) $$d\boldsymbol{Q}_1 + ...+ d\boldsymbol{Q}_K + d\boldsymbol{Q}_m = d\boldsymbol{Q}_d + d\boldsymbol{Q}_e$$

The first term in each equation (except market clearing) is multiplied by 1 in the form $\frac{\boldsymbol{QP}}{\boldsymbol{PQ}}$ so that the equations can be expressed in terms of price elasticities.

(1.2) $$d\boldsymbol{P} = \frac{\partial \boldsymbol{P}}{\partial \boldsymbol{Q}_k} \frac{\boldsymbol{Q}_k}{\boldsymbol{P}} \frac{\boldsymbol{P}}{\boldsymbol{Q}_k} d\boldsymbol{Q}_k + \frac{\partial \boldsymbol{P}}{\partial \boldsymbol{a}_k} d\boldsymbol{a}_k, \boldsymbol{k} = 1,...., \boldsymbol{K}$$

(2.2) $$d\boldsymbol{P} = \frac{\partial \boldsymbol{P}}{\partial \boldsymbol{Q}_m} \frac{\boldsymbol{Q}_m}{\boldsymbol{P}} \frac{\boldsymbol{P}}{\boldsymbol{Q}_m} d\boldsymbol{Q}_m + \frac{\partial \boldsymbol{P}}{\partial \boldsymbol{a}_m} d\boldsymbol{a}_m$$

(3.2) $$d\boldsymbol{P} = \frac{\partial \boldsymbol{P}}{\partial \boldsymbol{Q}_d} \frac{\boldsymbol{Q}_d}{\boldsymbol{P}} \frac{\boldsymbol{P}}{\boldsymbol{Q}_d} d\boldsymbol{Q}_d + \frac{\partial \boldsymbol{P}}{\partial \boldsymbol{b}_d} d\boldsymbol{b}_d$$

(4.2) $$dP = \frac{\partial P}{\partial Q_e}\frac{Q_e}{P}\frac{P}{Q_e}dQ_e + \frac{\partial P}{\partial b_e}db_e$$

(5.2) $$dQ_1 + ... + dQ_K + dQ_m = dQ_d + dQ_e$$

The greek characters ***epsilon*** $(\in)$ represent supply elasticities and ***eta*** (η) represent demand elasticities. Note that elasticities are defined as percentage change in quantity divided by percentage change in price. For example

$$\in = \frac{\%\Delta Q}{\%\Delta P} = \frac{\frac{\Delta Q}{Q}}{\frac{\Delta P}{P}} = \frac{\Delta Q}{\Delta P}\frac{P}{Q} \quad or \quad \frac{\partial Q}{\partial P}\frac{P}{Q}$$

Also, to simplify notation let $\frac{\partial P}{\partial a}da = \gamma$ and $\frac{\partial P}{\partial b}db = \beta$

where γ and β represent vertical shifts (shifts along the price axis, measured in dollars) in supply and demand curves, respectively. Changes in costs per unit of production and changes in consumers' willingness to pay for a unit of production can be inputted into the model via these shifters. The use of these shifters in modeling cross-commodity effects and trade effects is discussed below. Substituting the relationships described above into the system of equations we get

(1.3) $$dP = \frac{P}{\in_k Q_k}dQ_k + \gamma_k, k = 1,...,K$$

(2.3) $$dP = \frac{P}{\in_m Q_m}dQ_m + \gamma_m$$

(3.3) $$dP = \frac{P}{\eta_d Q_d}dQ_d + \beta_d$$

(4.3) $$d\boldsymbol{P} = \frac{\boldsymbol{P}}{\eta_e \boldsymbol{Q}_e} d\boldsymbol{Q}_e + \beta_e$$

(5.3) $$d\boldsymbol{Q}_1 + ... + d\boldsymbol{Q}_K + d\boldsymbol{Q}_m = d\boldsymbol{Q}_d + d\boldsymbol{Q}_e$$

The totally differentiated market equations are then solved for quantity changes:

(1.4) $$d\boldsymbol{Q}_k = \left(d\boldsymbol{P} - \gamma_k\right)\frac{\in_k \boldsymbol{Q}_k}{\boldsymbol{P}}, \boldsymbol{k} = 1, ...\boldsymbol{K}$$

(2.4) $$d\boldsymbol{Q}_m = (d\boldsymbol{P} - \gamma_m)\frac{\in_m \boldsymbol{Q}_m}{\boldsymbol{P}}$$

(3.4) $$d\boldsymbol{Q}_d = (d\boldsymbol{P} - \beta_d)\frac{\eta_d \boldsymbol{Q}_d}{\boldsymbol{P}}$$

(4.4) $$d\boldsymbol{Q}_e = (d\boldsymbol{P} - \beta_e)\frac{\eta_e \boldsymbol{Q}_e}{\boldsymbol{P}}$$

(5.4) $$d\boldsymbol{Q}_1 + ... + d\boldsymbol{Q}_K + d\boldsymbol{Q}_m = d\boldsymbol{Q}_d + d\boldsymbol{Q}_e$$

Solving the resulting system simultaneously gives a price change equation:

(6) $$\mathrm{d}\boldsymbol{P} = \left[\frac{\beta_d \eta_d \boldsymbol{Q}_d + \beta_e \eta_e \boldsymbol{Q}_e - \sum_{\boldsymbol{k}=1}^{\boldsymbol{K}} (\gamma_k \in_k \boldsymbol{Q}_k) - \gamma_m \in_m \boldsymbol{Q}_m}{\eta_d \boldsymbol{Q}_d + \eta_e \boldsymbol{Q}_e - \sum_{\boldsymbol{k}=1}^{\boldsymbol{K}} (\in_k \boldsymbol{Q}_k) - \in_m \boldsymbol{Q}_m}\right]$$

The price change equation **(6)** and the quantity change equations **(1.4)** through **(5.4)** are used to help implement the spreadsheet model. In other words, these equations actually appear in the spreadsheet software. The elasticities of export demand (η) and of import supply $(\in)$ for equation **(6)** will be defined below.

Modeling Cross-Commodity Effects

Cross-commodity effects are effects on the demand or supply of a commodity that result from price changes in commodities that are substitutes or complements **(Hirshleifer)**. These effects can occur on both the demand and supply sides of a market. For example, beef is a potential substitute for pork both on the demand and supply sides. If the price of beef goes up, consumers may demand more pork because it has become relatively cheaper, and vice-versa. Likewise, if the price of beef goes up, some producers may shift resources away from pork production into beef production, and vice-versa. Hamburgers and buns are a classic example of a complementary relationship on the demand side. The strength and nature (substitute or complement) of the relationship between the markets can be represented by cross-price elasticities.

Demand Side

Cross-commodity effects on the demand side in the domestic market are modeled via the demand shifter (β_d). Essentially, we want to solve for the demand shift that would result from a price change in a related market. Solving equation **(3.4)** for β_d yields

(7) $$\beta_d = d\boldsymbol{P} - \frac{\boldsymbol{P}}{\eta_d \boldsymbol{Q}_d}\; d\boldsymbol{Q}_d$$

The change in quantity demanded is obtained from the cross-price elasticity of demand and the price change in the related market (j) as shown in **(8)**.

(8) $$d\boldsymbol{Q}_d = \boldsymbol{Q}_d \eta_{dj} \frac{d\boldsymbol{P}_j}{\boldsymbol{P}_j}$$

Substituting **(8)** into **(7)** yields

(9) $$\beta_d = d\boldsymbol{P} - \frac{\boldsymbol{P}}{\eta_d \boldsymbol{Q}_d}\; \boldsymbol{Q}_d \eta_{dj}\; \frac{d\boldsymbol{P}_j}{\boldsymbol{P}_j}$$

Substituting the price change equation **(6)** into **(9)**, setting all supply shifters and the foreign demand shifter to zero and rearranging yields

(10) $$\beta_d = \left[\frac{-\dfrac{\boldsymbol{P}}{\eta_d \boldsymbol{Q}_d} \boldsymbol{Q}_d \eta_{dj} \dfrac{d\boldsymbol{P}_j}{\boldsymbol{P}_j}}{1 - \dfrac{\eta_d \boldsymbol{Q}_d}{\eta_d \boldsymbol{Q}_d + \eta_e \boldsymbol{Q}_e - \sum_{k=1}^{K} (\in_k \boldsymbol{Q}_k) - \in_m \boldsymbol{Q}_m}} \right]$$

The demand shift equation **(10)** is used to help implement the spreadsheet model.

Modeling Derived Demand for Inputs

The spreadsheet model is capable of analyzing vertical market effects, such as changes in the derived demand for inputs into commodity production. For example, a change in the price of beef will affect the demand for the corn which serves as an input into beef production. These effects are modeled by calculating a cross-price demand elasticity for inputs based on the share of total production of the input used in the production of other modeled commodities. This calculated elasticity is used in equation **(10)** as η_{dj} .

The first step in calculating this elasticity is to calculate the percentage change in the quantity of the input demanded. This percentage change is obtained by multiplying the share of the input used in the production of each modeled commodity by the percentage change in the equilibrium quantity supplied of that commodity that results from the modeled policy or activity change. Or in other words, the share is multiplied by the percentage change in quantity supplied determined by the model. This is shown in equation **(10.1).**

(10.1)
$$\frac{d\boldsymbol{Q_d}}{\boldsymbol{Q_d}} = \sum_{\boldsymbol{i}=1}^{\boldsymbol{n}} \alpha_i \frac{d\boldsymbol{Q_i}}{\boldsymbol{Q_i}}$$

where $\boldsymbol{Q_d}$ in this case is the quantity demanded of the input, α_i is the share of the input used in the production of commodity $\boldsymbol{i}$ and $\boldsymbol{Q_i}$ is the quantity supplied of commodity $\boldsymbol{i}$ which uses the input in its production process.

The second step is to divide both sides of equation **(10.1)** by the percentage change in the price of the commodity directly affected by the policy or activity change. Since we are examining a change in derived input demand due to a change in output price there is a direct relationship (a positive elasticity) between the output price and the quantity demanded of the input. As output price rises, the quantity supplied of the output also rises increasing the demand for inputs required to produce the output. The result is shown in equation **(10.2)**.

(10.2)
$$\frac{d\boldsymbol{Q_d}}{\boldsymbol{Q_d}} \frac{\boldsymbol{P}}{d\boldsymbol{P}} = -\frac{\boldsymbol{P}}{d\boldsymbol{P}} \sum_{\boldsymbol{i}=1}^{\boldsymbol{n}} \alpha_i \frac{d\boldsymbol{Q_i}}{\boldsymbol{Q_i}}$$

Supply Side

Cross-commodity effects on the supply side in the domestic market are modeled via the supply shifters (γ_k). Essentially we want to solve for the supply shift that would result from a price change in a related market. Solving equation **(1.4)** for γ_k yields

$$\gamma_k = dP - \frac{P}{\in_k Q_k} dQ_k \tag{11}$$

The change in quantity supplied is obtained from the cross price elasticity of supply and the price change in the related market (j) as shown in **(12)**.

$$dQ_k = Q_k \in_{kj} \frac{dP_j}{P_j} \tag{12}$$

Substituting **(12)** into **(11)** yields

$$\gamma_k = dP - \frac{P}{\in_k Q_k} Q_k \in_{kj} \frac{dP_j}{P_j} \tag{13}$$

Substituting **(6)** into **(13)**, setting all demand shifters and the foreign supply shifter to zero and rearranging yields

$$\gamma_k = \left[\frac{-\frac{P}{\in_k Q_k} Q_k \in_{kj} \frac{dP_j}{P_j}}{\left[1 - \frac{-\in_k Q_k}{\eta_d Q_d + \eta_e Q_e - \sum_{k=1}^{K} (\in_k Q_k) - \in_m Q_m} \right]} \right] \tag{14}$$

The supply shift equation **(14)** is used to help implement the spreadsheet model.

Modeling Trade Effects

The spreadsheet model can be used to analyze changes in trade policy. For example, the imposition of sanitary or phytosanitary risk mitigation measures on traded goods may increase the price of the goods in the importing country. The effects of this imposition on market prices and quantities, as well as on consumer and producer surplus, can be analyzed. The model contains both a domestic country and a foreign country. Each of these countries has a Rest-of-the-World component associated with it to account for trade diversion and displacement effects on other countries. For example, a reduction in the costs of mitigating the risk of the domestic country's imports from the foreign country may cause the foreign country to divert exports from lower-priced third-country markets to the higher priced domestic country market.

The domestic country can be modeled as either an exporter or an importer. Trade effects are modeled via the foreign demand shifter (β_e) and the foreign supply shifter (γ_m).

The foreign demand shifter is used for the situation where the domestic country is an exporter. Derivation of the foreign demand shifter is analogous to the derivation of the domestic demand shifter shown in **(10)**. Essentially, we want to solve for the demand shift that would result from a price change in a foreign country. Solving equation **(4.4)** for β_e yields

(15) $$\beta_e = d\boldsymbol{P} - \frac{\boldsymbol{P}}{\eta_e \boldsymbol{Q}_e}\, d\boldsymbol{Q}_e$$

We can use the excess demand elasticity of the foreign importing country or region to estimate part of the change in domestic exports. Excess demand for a commodity is the difference between what is consumed or demanded in the domestic country and what is produced or supplied (**Figure 3)**.

The foreign country's commodity price in the following derivation is represented by $\boldsymbol{P}_f$. The excess demand (X_d) elasticity is derived as follows.

(16) $$X_d\left(\boldsymbol{P}_f\right) = \boldsymbol{Q}_d\left(\boldsymbol{P}_f\right) - \boldsymbol{Q}_s\left(\boldsymbol{P}_f\right)$$

The excess demand equation **(16)** is totally differentiated.

(17) $$dX_d = \frac{\partial \boldsymbol{Q}_d}{\partial \boldsymbol{P}_f} d\boldsymbol{P}_f - \frac{\partial \boldsymbol{Q}_s}{\partial \boldsymbol{P}_f} d\boldsymbol{P}_f$$

Both sides of **(17)** are multiplied by $\frac{\boldsymbol{P_f}}{d\boldsymbol{P_f}X_d}$ so that it may be expressed in elasticity form.

(18) $$\frac{dX_d}{d\boldsymbol{P_f}}\frac{\boldsymbol{P_f}}{X_d} = \frac{\partial \boldsymbol{Q_d}}{\partial \boldsymbol{P_f}}\frac{\boldsymbol{P_f}}{\boldsymbol{Q_d}}\frac{\boldsymbol{Q_d}}{X_d}\frac{d\boldsymbol{P_f}}{d\boldsymbol{P_f}} - \frac{\partial \boldsymbol{Q_s}}{\partial \boldsymbol{P_f}}\frac{\boldsymbol{P_f}}{\boldsymbol{Q_s}}\frac{\boldsymbol{Q_s}}{X_d}\frac{d\boldsymbol{P_f}}{d\boldsymbol{P_f}}$$

The excess demand elasticity (η_x) is thus expressed as a function of the foreign country's demand elasticity (η_d), supply elasticity $(\in_s)$, consumption $(\boldsymbol{Q_d})$, production $(\boldsymbol{Q_s})$ and imports (X_d)

(19) $$\eta_x = \eta_d \frac{\boldsymbol{Q_d}}{X_d} - \in_s \frac{\boldsymbol{Q_s}}{X_d}$$

Note that

(20) $$\eta_x = \frac{dX_d}{d\boldsymbol{P_f}}\frac{\boldsymbol{P_f}}{X_d}$$

and

(20.1) $$d\boldsymbol{Q_e} = dX_d + A_v$$

Where A_v is a measure of the diversion of the domestic country's exports from the Rest of the World (ROW) to the foreign country.

Equation **(20.1)** basically says that the change in the domestic country's exports is equal to the change in the excess demand function of the foreign country less the amount of the domestic country's exports diverted from the Rest of the World (ROW) to the foreign country. A_v, as described below, will have a negative sign due to the direction of the foreign country's price change in this situation.

Therefore, the domestic country's change in exports can be expressed as

$$(21) \qquad d\boldsymbol{Q}_e = X_d \eta_x \frac{d\boldsymbol{P}_f}{\boldsymbol{P}_f} + A_v$$

where

$$(21.1) \qquad A_v = \left(-\left(-\left(1 - \boldsymbol{S}_{DOM,ROW}\right) * \sigma_{ROW} + \boldsymbol{S}_{DOM,ROW} * \eta_{ROW}\right) * X_{DOM,ROW}\right) * \left(\frac{d\boldsymbol{P}_f}{\boldsymbol{P}_f}\right)$$

$\boldsymbol{S}_{DOM,ROW}$ = the share of the domestic country's exports in ROW imports.

σ_{ROW} = the elasticity of substitution among sources of ROW imports.

η_{ROW} = ROW's elasticity of demand.

$X_{DOM,ROW}$ = the existing trade flow from the domestic country to ROW.

See **Armington (1969a)** for the derivation of equation **(21.1).**

Substituting **(21)** into **(15)** yields

$$(22) \qquad \beta_e = d\boldsymbol{P} - \frac{\boldsymbol{P}}{\eta_e \boldsymbol{Q}_e} \left(X_d \eta_x \frac{d\boldsymbol{P}_f}{\boldsymbol{P}_f} + A_v \right)$$

Substituting the price change equation **(6)** into **(22)**, setting all supply shifters and the domestic demand shifter to zero and rearranging yields

$$(23) \qquad \beta_e = \left[\frac{-\dfrac{\boldsymbol{P}}{\eta_e \boldsymbol{Q}_e} \left(X_d \eta_x \dfrac{d\boldsymbol{P}_f}{\boldsymbol{P}_f} + A_v \right)}{\left[1 - \dfrac{\eta_e \boldsymbol{Q}_e}{\eta_d \boldsymbol{Q}_d + \eta_e \boldsymbol{Q}_e - \sum_{k=1}^{K} (\in_k \boldsymbol{Q}_k) - \in_m \boldsymbol{Q}_m} \right]} \right]$$

The foreign demand shift equation **(23)** is used to help implement the spreadsheet model. The magnitude of the foreign demand shift is determined by the change in the commodity price in the foreign country (P_f) expected from a trade policy change. The elasticities of export demand (η_e) and of import supply $(\in_m)$ for equation **(23)** will be defined below.

The foreign supply shifter is used in the situation where the domestic country is modeled as an importer. Derivation of the foreign supply shifter is analogous to the derivation of the domestic supply shifter shown in **(14)**. Essentially, we want to solve for the supply shift that would result from a price change in a foreign country. Solving equation **(2.4)** for γ_m yields

(24) $$\gamma_m = dP - \frac{P}{\in_m Q_m} dQ_m$$

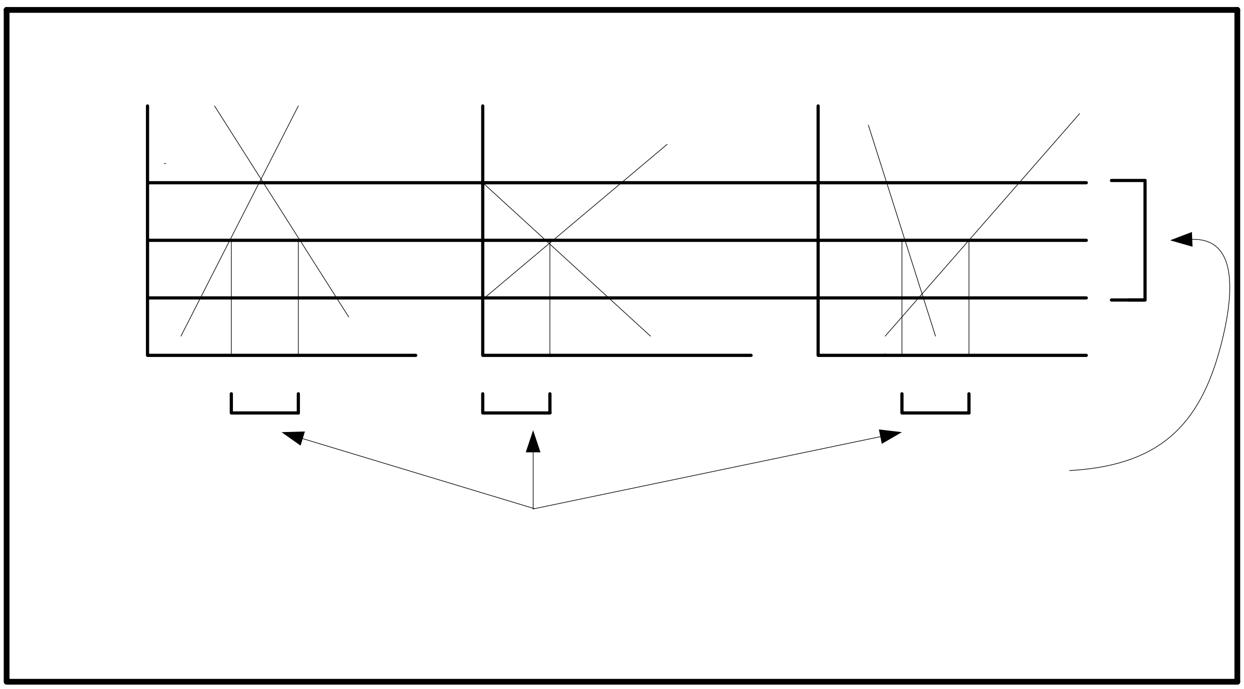

Figure 3. Illustration of excess supply and demand curves and their relationship to domestic supply and demand.

We can use the excess supply elasticity of the exporting country or region to estimate the change in imports. Excess supply for a commodity is the difference between what is produced or supplied in the domestic country and what is consumed or demanded **(Figure 3).**

The excess supply elasticity is derived as follows.

(25) $$X_s\left(\boldsymbol{P_f}\right) = \boldsymbol{Q_s}\left(\boldsymbol{P_f}\right) - \boldsymbol{Q_d}\left(\boldsymbol{P_f}\right)$$

The excess supply equation **(25)** is totally differentiated.

(26) $$d\,X_s = \frac{\partial \boldsymbol{Q_s}}{\partial \boldsymbol{P_f}} d\boldsymbol{P_f} - \frac{\partial \boldsymbol{Q_d}}{\partial \boldsymbol{P_f}} d\boldsymbol{P_f}$$

Both sides of **(26)** are multiplied by $\frac{\boldsymbol{P_f}}{d\boldsymbol{P_f} X_s}$ so that it may be expressed in elasticity form.

(27) $$\frac{d\,X_s \boldsymbol{P_f}}{d\boldsymbol{P_f} X_s} = \frac{\partial \boldsymbol{Q_s} \boldsymbol{P_f}}{\partial \boldsymbol{P_f} \boldsymbol{Q_s}} \frac{\boldsymbol{Q_s} d\boldsymbol{P_f}}{X_s d\boldsymbol{P_f}} - \frac{\partial \boldsymbol{Q_d} \boldsymbol{P_f}}{\partial \boldsymbol{P_f} \boldsymbol{Q_d}} \frac{\boldsymbol{Q_d} d\boldsymbol{P_f}}{X_s d\boldsymbol{P_f}}$$

The excess supply elasticity *($\in_x$)* is thus expressed as a function of the foreign country's supply elasticity $\left(\in_s\right)$, demand elasticity $\left(\eta_d\right)$, production $\left(\boldsymbol{Q_s}\right)$, consumption $\left(\boldsymbol{Q_d}\right)$, and exports $\left(X_s\right)$.

(28) $$\in_x = \in_s \frac{\boldsymbol{Q_s}}{X_s} - \eta_d \frac{\boldsymbol{Q_d}}{X_s}$$

Note that

(29) $$\in_x = \frac{dX_s \boldsymbol{P_f}}{d\boldsymbol{P_f} X_s}$$

(29.1) $$d\boldsymbol{Q_m} = d\,X_s + A_v + A_d$$

where A_v is a measure of the diversion of the foreign country's exports from the Rest of the World (ROW) to the domestic country and A_d is a measure of the displacement of the domestic country's imports from ROW by the foreign country's exports.

Equation **(29.1)** basically says that the change in the domestic country's imports is equal to the change in the foreign country's excess supply function (trade creation) plus the quantity of the foreign country's exports diverted from the Rest of the World (ROW) to the domestic country (trade diversion) less the quantity of the domestic country's imports from ROW displaced by the foreign country's exports (trade displacement). A_v as described below, will have a positive sign (due to the direction of the foreign country's price change) while A_d will have a negative sign.

Therefore, the domestic country's change in imports can be expressed as

$$(30) \qquad d\boldsymbol{Q_m} = X_s \in_x \frac{d\boldsymbol{P_f}}{\boldsymbol{P_f}} + \boldsymbol{A_v} + \boldsymbol{A_d}$$

where

$$(30.1) \qquad A_v = \left(-\left(-\left(1 - S_{FOR,ROW}\right) * \sigma_{ROW} + \boldsymbol{S}_{FOR,ROW} * \eta_{ROW}\right) * X_{FOR,ROW}\right) * \left(\frac{d\boldsymbol{P}_f}{\boldsymbol{P}_f}\right)$$

$$(30.2) \qquad A_d = \left(S_{FOR,DOM} * \sigma_{DOM} + S_{FOR,DOM} * \eta_d\right) * X_{ROW,DOM} * \left(\frac{\boldsymbol{P_f} - \boldsymbol{P}_{ROW}}{\boldsymbol{P_f}}\right)$$

and

$\boldsymbol{S}_{FOR,ROW}$ = the share of the foreign country's exports in ROW imports
σ_{ROW} = the elasticity of substitution among sources of ROW imports.
η_{ROW} = ROW's elasticity of demand.
$X_{FOR,ROW}$ = the existing trade flow from the foreign country to ROW.
$\boldsymbol{S}_{FOR,DOM}$ = the share of the foreign country's exports in the domestic country's imports.
σ_{DOM} = the elasticity of substitution among sources of the domestic country's imports.
$X_{ROW,DOM}$ = the existing trade flow from ROW to the domestic country.

See **Armington (1969a)** for the derivation of equations **(30.1 and 30.2)**.

Substituting **(30)** into **(24)** yields

$$(31) \qquad \gamma_m = d\boldsymbol{P} - \frac{\boldsymbol{P}}{\in_m \boldsymbol{Q_m}}\left(X_s \in_x \frac{d\boldsymbol{P_f}}{\boldsymbol{P_f}} + A_v + A_d\right)$$

Substituting the price change equation **(6)** into **(31),** setting all demand shifters and the domestic supply shifter to zero and rearranging yields

(32) $$\gamma_m = \left[\frac{ -\dfrac{P}{\in_m Q_m}\left(x_s \in_x \dfrac{dP_f}{P_f} + A_v + A_d \right) }{ \left[1 - \dfrac{-\in_m Q_m}{\eta_d Q_d + \eta_e Q_e - \sum_{k=1}^{K} (\in_k Q_k) - \in_m Q_m} \right] } \right]$$

The foreign supply shift equation **(32)** is used to help implement the spreadsheet model. The magnitude of the foreign supply shift is determined by the change in the commodity price in the foreign country (P_f) expected from a trade policy change. The elasticities of export demand (η_e) and of import supply $(\in_m)$ for equation **(32)** will be defined below.

The spreadsheet model contains both a domestic country model and a foreign country model, as well as equations representing a Rest-of-the-World importing or exporting region for each country. The foreign country model is a reproduction of the domestic country model described above, except for slight differences in the foreign supply and demand shifters to enable the linkages to the domestic country model. For convenience, the Rest-of-the World equations for both the domestic and the foreign country are contained entirely in the domestic country model and linked to the foreign country model through its foreign supply and demand shifters.

Export Demand and Import Supply Elasticities

The elasticity of export demand (η_e) is derived in an analogous manner to the derivation of the excess demand elasticity. The domestic country's exports are defined as the sum of the excess demand functions of major importing countries or regions less the sum of the excess supply functions of major exporting countries or regions excluding the domestic country being considered **(Bredahl and others)**. The elasticity of export demand is thus derived as follows (**i** represents importing countries or regions and **l** represents exporting countries or regions):

(33) $$Q_e(P) = \sum_{i=1}^{n} \left[X_{di}\left(P_{fi}(P) \right) \right] - \sum_{l=1}^{r} \left[X_{sl}\left(P_{fl}(P) \right) \right]$$

where

(34) $$X_{di}\left(\boldsymbol{P_{fi}}\left(\boldsymbol{P}\right)\right)=\boldsymbol{Q_{di}}\left(\boldsymbol{P_{fi}}\left(\boldsymbol{P}\right)\right)-\boldsymbol{Q_{si}}\left(\boldsymbol{P_{fi}}\left(\boldsymbol{P}\right)\right)$$

and

(35) $$X_{sl}\left(\boldsymbol{P_{fl}}\left(\boldsymbol{P}\right)\right)=\boldsymbol{Q_{sl}}\left(\boldsymbol{P_{fl}}\left(\boldsymbol{P}\right)\right)-\boldsymbol{Q_{dl}}\left(\boldsymbol{P_{fl}}\left(\boldsymbol{P}\right)\right)$$

Note that the foreign price is expressed as a function of domestic price.

The export demand equation **(33)** is totally differentiated.

(36) $$d\boldsymbol{Q_e}=\sum_{i=1}^{n}\left[\frac{\partial X_{di}}{\partial \boldsymbol{P_{fi}}}\frac{\partial \boldsymbol{P_{fi}}}{\partial \boldsymbol{P}}d\boldsymbol{P}\right]-\sum_{l=1}^{r}\left[\frac{\partial X_{sl}}{\partial \boldsymbol{P_{fl}}}\frac{\partial \boldsymbol{P_{fl}}}{\partial \boldsymbol{P}}d\boldsymbol{P}\right]$$

Both sides of **(36)** are multiplied by $\frac{\boldsymbol{P}}{d\boldsymbol{P}\boldsymbol{Q_e}}$ so that it may be expressed in elasticity form.

(37) $$\frac{d\boldsymbol{Q_e}}{d\boldsymbol{P}}\frac{\boldsymbol{P}}{\boldsymbol{Q_e}}=\sum_{i=1}^{n}\left[\frac{\partial X_{di}}{\partial \boldsymbol{P_{fi}}}\frac{\boldsymbol{P_{fi}}}{X_{di}}\frac{\partial \boldsymbol{P_{fi}}}{\partial \boldsymbol{P}}\frac{\boldsymbol{P}}{\boldsymbol{P_{fi}}}\frac{X_{di}}{\boldsymbol{Q_e}}\frac{d\boldsymbol{P}}{d\boldsymbol{P}}\right]-\sum_{l=1}^{r}\left[\frac{\partial X_{sl}}{\partial \boldsymbol{P_{fl}}}\frac{\boldsymbol{P_{fl}}}{X_{sl}}\frac{\partial \boldsymbol{P_{fl}}}{\partial \boldsymbol{P}}\frac{\boldsymbol{P}}{\boldsymbol{P_{fl}}}\frac{X_{sl}}{\boldsymbol{Q_e}}\frac{d\boldsymbol{P}}{d\boldsymbol{P}}\right]$$

The export demand elasticity (η_e) is thus expressed as a function of the foreign countries' excess demand elasticities (η_x), excess supply elasticities $(\in_x)$, imports (X_d) exports (X_s) price transmission elasticities $(\in_p)$; and the export level of the domestic country under consideration $(\boldsymbol{Q_e})$

(38) $$\eta_e=\sum_{i=1}^{n}\left[\eta_{xi}\in_{pi}\frac{X_{di}}{\boldsymbol{Q_e}}\right]-\sum_{l=1}^{r}\left[\in_{xl}\in_{pl}\frac{X_{sl}}{\boldsymbol{Q_e}}\right]$$

The elasticity of import supply $(\in_m)$ is derived in an analogous manner to the derivation of the excess supply elasticity. The domestic country's imports are defined as the sum of the excess supply functions of major exporting countries or regions less the sum of the excess demand functions of major importing countries or regions excluding the domestic country being considered **(Bredahl and others)**. (**l** represents exporting countries or regions and **i** represents importing countries or regions):

(39) $$Q_m(P) = \sum_{l=1}^{r}\left[X_{sl}\left(P_{fl}\left(P\right)\right)\right] - \sum_{i=1}^{n}\left[X_{di}\left(P_{fi}\left(P\right)\right)\right]$$

The import supply equation **(39)** is totally differentiated.

(40) $$d\,Q_m = \sum_{l=1}^{r}\left[\frac{\partial X_{sl}}{\partial P_{fl}}\frac{\partial P_{fl}}{\partial P}dP\right] - \sum_{i=1}^{n}\left[\frac{\partial X_{di}}{\partial P_{fi}}\frac{\partial P_{fi}}{\partial P}dP\right]$$

Both sides of *(40)* are multiplied by $\frac{P}{dPQ_m}$ so that it may be expressed in elasticity form.

(41) $$\frac{d\,Q_m}{dP}\frac{P}{Q_m} = \sum_{l=1}^{r}\left[\frac{\partial X_{sl}}{\partial P_{fl}}\frac{P_{fl}}{X_{sl}}\frac{\partial P_{fl}}{\partial P}\frac{P}{P_{fl}}\frac{X_{sl}}{Q_m}\frac{dP}{dP}\right] - \sum_{i=1}^{n}\left[\frac{\partial X_{di}}{\partial P_{fi}}\frac{P_{fi}}{X_{di}}\frac{\partial P_{fi}}{\partial P}\frac{P}{P_{fi}}\frac{X_{di}}{Q_m}\frac{dP}{dP}\right]$$

The import supply elasticity $(\in_m)$ is thus expressed as a function of the foreign countries' excess supply elasticities $(\in_x)$, excess demand elasticities (η_x), exports $\left(X_s\right)$ imports $\left(X_d\right)$, price transmission elasticities $(\in_p)$, and the import level of the domestic country under consideration (Q_m)

(42) $$\in_m = \sum_{l=1}^{r}\left[\in_{xl}\in_{pl}\frac{X_{sl}}{Q_m}\right] - \sum_{i=1}^{n}\left[\eta_{xi}\in_{pi}\frac{X_{di}}{Q_m}\right]$$

Deriving the Surplus Equations

Consumer and producer surplus equations can be derived based on the assumption that demand and supply functions are approximately linear near the initial equilibrium point. For small shifts, this assumption will result in reasonably accurate estimates of consumer and producer surplus change, regardless of the true form of the demand and supply functions. The assumption of linearity simplifies the derivation as shown below.

Using the Linearity Assumption

From the linear equation

(43) $$\boldsymbol{P = x + yQ}$$

we get

(44) $$\frac{\partial \boldsymbol{P}}{\partial \boldsymbol{Q}} = \boldsymbol{y}, \qquad \frac{\partial \boldsymbol{P}}{\partial \boldsymbol{Q}} \frac{\boldsymbol{Q}}{\boldsymbol{P}} = \boldsymbol{y} \frac{\boldsymbol{Q}}{\boldsymbol{P}} = \frac{1}{\in}$$

Solving for the slope of the linear equation (y) we get

(45) $$\boldsymbol{y} = \frac{\boldsymbol{P}}{\boldsymbol{Q} \in}$$

Substituting (45) into (43) we get

(46) $$\boldsymbol{P} = \boldsymbol{x} + \frac{\boldsymbol{P}}{\boldsymbol{Q} \in} \boldsymbol{Q}$$

Solving **(46)** for the intercept on the price axis (x) we get

(47) $$\boldsymbol{x} = \boldsymbol{P} - \frac{\boldsymbol{P}}{\boldsymbol{Q} \in} \boldsymbol{Q} = \boldsymbol{P} - \frac{\boldsymbol{P}}{\in}$$

Equations **(45)** and **(47)** are used to help derive the consumer and producer surplus equations.

Producer Surplus

Producer surplus changes can result from either shifts in demand or shifts in supply **(Figure 4)**. Shifts in demand might occur as a result of changes in related markets as well as changes in the tastes and preferences of consumers. Shifts in supply might occur as a result of a change in disease status of a producer's operation as well as changes in related markets. The following derivation provides equations that measure producer surplus changes that might occur from any of these sources.

Assuming linear supply and demand functions, the area of the triangle representing the original producer surplus (prior to any change) can be measured as the distance between the equilibrium price line and the intercept on the price axis (x) times the equilibrium quantity times one half.

(48) $$\boldsymbol{PS_o} = \frac{1}{2}\left(\boldsymbol{P_o} - x_o\right)\boldsymbol{Q_o} = \frac{1}{2}\left(\boldsymbol{P_o} - \boldsymbol{P_o} + \frac{\boldsymbol{P_o}}{\in}\right)\boldsymbol{Q_o} = \frac{\boldsymbol{P_o Q_o}}{2\in}$$

Note that after a parallel shift the new intercept can be determined from **(47)** using the new equilibrium price and quantity and the slope from the original curve so that

(49) $$\boldsymbol{x_n} = \boldsymbol{P_n} - \frac{\boldsymbol{P_o}}{\boldsymbol{Q_o}\in}\boldsymbol{Q_n}$$

Therefore, the new producer surplus can be measured as

(50) $$\boldsymbol{PS_n} = \frac{1}{2}\left(\boldsymbol{P_n} - \boldsymbol{x_n}\right)\boldsymbol{Q_n} = \frac{1}{2}\left(\boldsymbol{P_n} - \boldsymbol{P_n} + \frac{\boldsymbol{P_o}}{\boldsymbol{Q_o}\in}\boldsymbol{Q_n}\right)\boldsymbol{Q_n} = \frac{\boldsymbol{P_o Q_n^2}}{2\in\boldsymbol{Q_o}}$$

Change in producer surplus can therefore be measured as

(51) $$\Delta\boldsymbol{PS} = \boldsymbol{PS_n} - \boldsymbol{PS_o} = \frac{\boldsymbol{P_o Q_n^2}}{2\in\boldsymbol{Q_o}} - \frac{\boldsymbol{P_o Q_o^2}}{2\in\boldsymbol{Q_o}} = \frac{\boldsymbol{P_o}\left(\boldsymbol{Q_n^2} - \boldsymbol{Q_o^2}\right)}{2\in\boldsymbol{Q_o}}$$

To express producer surplus change in terms of the original equilibrium quantity, note that

(52) $$\boldsymbol{Q_n^2} = \left(\boldsymbol{Q_o} + \boldsymbol{dQ}\right)^2 = \boldsymbol{Q_o^2} + 2\boldsymbol{Q_o dQ} + \boldsymbol{dQ}^2$$

Substituting **(52)** into **(51)** we get

(53) $$\Delta \boldsymbol{PS} = \frac{\boldsymbol{P_o}\left(2\boldsymbol{Q_o dQ} + \boldsymbol{dQ}^2\right)}{2 \in \boldsymbol{Q_o}}$$

Unlike the producer surplus change equation discussed in **Lichtenberg and others**, **Ebel and others**, and **Forsythe and Corso**, equation **(53)** will measure producer surplus change for shifts in either supply or demand or both. The equation applies to each of the $\boldsymbol{K}$ producer groups, including those producers who are producing for foreign markets.

Consumer Surplus

Change in consumer surplus can be measured in a manner similar to produce surplus change **(Figure 5).** The original consumer surplus is measured as

(54) $$\boldsymbol{CS_o} = \frac{1}{2}\left(x_o - \boldsymbol{P_o}\right)\boldsymbol{Q_o} = \frac{1}{2}\left(\boldsymbol{P_o} - \frac{\boldsymbol{P_o}}{\eta} - \boldsymbol{P_o}\right)\boldsymbol{Q_o} = -\frac{\boldsymbol{P_o Q_o}}{2\eta}$$

The new consumer surplus can be measured as

(55) $$\boldsymbol{CS_n} = \frac{1}{2}\left(\boldsymbol{x_n} - \boldsymbol{P_n}\right)\boldsymbol{Q_n} = \frac{1}{2}\left(\boldsymbol{P_n} - \frac{\boldsymbol{P_o}}{\boldsymbol{Q}_o\eta}\boldsymbol{Q_n} - \boldsymbol{P_n}\right)\boldsymbol{Q_n} = -\frac{\boldsymbol{P_o Q_n^2}}{2\eta \boldsymbol{Q}_o}$$

Change in consumer surplus can therefore be measured as

(56) $$\Delta CS = -\frac{\boldsymbol{P}_o\boldsymbol{Q}_n^2}{2\eta\boldsymbol{Q}_o} + \frac{\boldsymbol{P}_o\boldsymbol{Q}_o^2}{2\eta\boldsymbol{Q}_o} = \frac{\boldsymbol{P_o}\left(\boldsymbol{Q_o^2} - \boldsymbol{Q}_n^2\right)}{2\eta\boldsymbol{Q}_o} = -\frac{\boldsymbol{P_o}\left(\boldsymbol{2Q_o dQ} + \boldsymbol{dQ^2}\right)}{2\eta\boldsymbol{Q}_o}$$

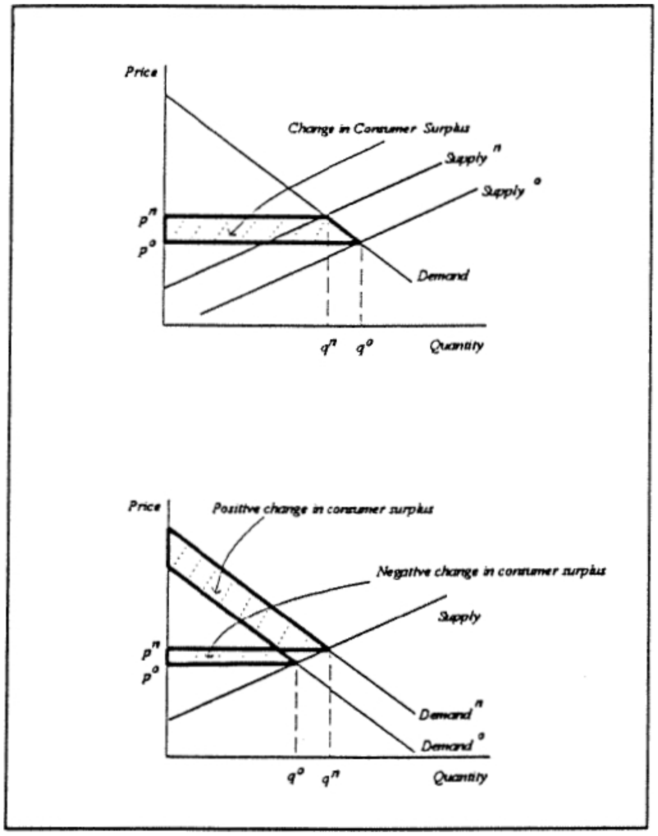

Figure 5. Consumer surplus changes

Modeling Shifts over Time

Following a procedure used by **Miller and others(1994)** shifts in supply in a given region that result from a change in herd status are weighted over time by the proportion of affected herds in that region in a given time period. For example, if a change in herd status from affected to non-affected results in an average $1 per marketed head cost savings to the producer and 50 percent of the operations in a given producer group $(\boldsymbol{k})$ are classified as affected in a given time period, then for that group in that time period the vertical supply shift (γ_k) will be -$0.50. In a time period when all of the operations in a producer group unaffected then the vertical supply shift will be -$1. Welfare changes are calculated for each time period. All welfare changes are discounted to adjust for the time value of money.

Measuring the welfare changes for the time frame between steady states and into perpetuity involves a three step calculation process. First, perpetual welfare changes are calculated using the method described in **Ebel and others**. This method measures changes into perpetuity and assumes that the movement between steady states occurs instantaneously with no time period required for gradual adjustment to the new steady state. Second, welfare changes are calculated over the relevant time period (the time it takes to move to a new steady state or to eradication) assuming an instantaneous move to

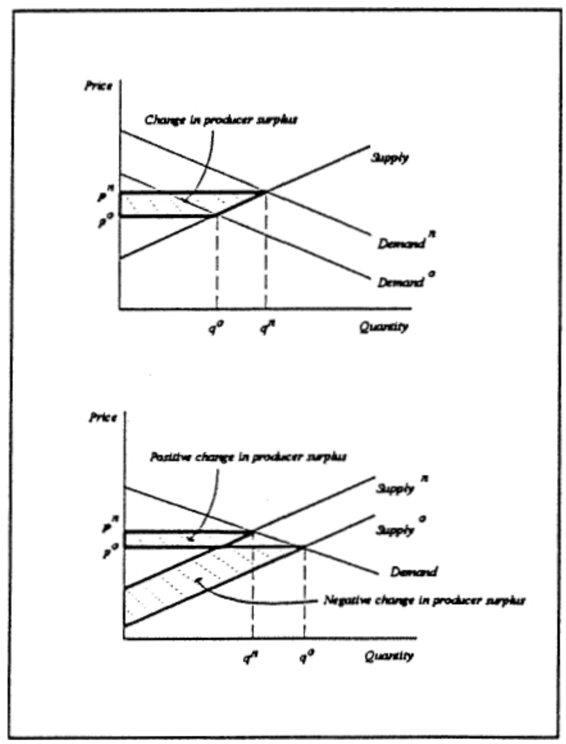

Figure 4. Producer surplus changes.

the new steady state or, in other words, that the full supply shift occurs immediately. Unlike the prior calculation, however, this second calculation does not extend the measurement of changes into perpetuity.

Finally, the welfare changes are measured over the relevant time period using the weighted supply shifts described above. The value for the welfare changes into perpetuity are then obtained by subtracting the values obtained in the second calculation from the values obtained in the first calculation and then added them to the results obtained using the weighted shift.

CLOSING SUMMARY

The model described herein meets the requirements for routine policy assessments described by Lichtenberg and others. It is capable of producing results on short notice. The results that it produces provide information about the efficiency impacts of alternative policies, measured by changes in net social surplus. It provides information about the distributional effects of proposed policies. And, it uses data provided by natural scientists, including veterinarians, entomologists, and plant pathologists that are often developed without regard to economic needs. By meeting these requirements the model provides a useful tool for regulatory analysts to conduct routine, quick turnaround policy assessments.

REFERENCES

Armington, P.S. "A Theory of Demand for Products Distinguished by Place of Production." *International Monetary Fund Staff Papers.* 16(1969a): 159-178.

Bredahl, M.E., W.H. Meyers, and K.J. Collins. "The Elasticity of Foreign Demand for U.S. Agricultural Products: The Importance of the Price Transmission Elasticity." *Amer. J. Agr. Econ.* 61(February 1979):58-63.

Ebel, E.D., R.H. Hornbaker, and C.H. Nelson. "Welfare Effects of the National Pseudorabies Eradication Program." *Amer. J. Agr. Econ.*- 74(August 1992):638-45.

Forsythe, K.W., and B.A. Corso. "Welfare Effects of the National Pseudorabies Eradication Program: Comment." *Amer. J. Agr. Econ.* 76(November 1994):968-71.°

Hirshleifer, J. 1984. Price Theory and Applications, 3rd ed: Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Lichtenberg, E., D. D. Parker, and D. Zilberman. "Marginal Analysis of Welfare Cost of Environmental Policies: The Case of Pesticide Regulation." *Amer. J. Agr. Econ.* 70(November 1988):867-74.

Miller, G.Y., D.L. Forster and J. Tsai. "A Benefit-Cost Analysis of the National Pseudorabies Program." Final Report from Contract No. 53-6395-2-114, RF Project No. 760341/726861, USDA Animal and Plant Health Inspection Service, Hyattsville, MD, and The Ohio State University, Department of Veterinary Preventive Medicine and Department of Agricultural Economics and Rural Sociology, June 1994.